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WATER ABSORPTION AND SALT ATTACK RESISTANCE OF COAL ASH BRICK MADE OF DIFFERENT PERCENTAGE OF FOAM CONTENT

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ABSTRACT

Coal ash which constitute of fly ash and bottom ash were proved to be used as main component in brick production. However, published work on the coal ash brick with addition of foam in order to produce lightweight brick is still lacking. This thesis reports the effect of variation in foam content in coal ash brick on the density, water absorption and salt attack resistance. Comparison of those parameters was made between the coal ash bricks and conventional brick. The coal ash brick mixes were formulated using industrial by-product, ground granulated blastfurnace slag (GGBS) which is activated with an alkaline (hydrated lime or Portland cement) combined with coal ash from coal-fired thermal power plant. The blended binder comprising of hydrated lime (HL) – GGBS and Portland cement (PC) –GGBS were used to stabilize the coal ash brick. Foam was used to produce lightweight brick. The percentage of foam added to the brick mixes are 25%, 50% and 75%. A total of sixty (60) brick specimen subjected to ten (10) series of mix proportion were cast and put in air curing condition for at least 28 days before testing. The density measurement in accordance with AS/NZS 4456.8, water absorption test in accordance with BS EN 772-21 and salt attack resistance in accordance with AS/NZS 4456.10 were evaluated on the brick specimens. The results indicated that the density of coal ash brick decreases with the increase in foam content. Also for bricks composed of both blended binder, the water absorption were directly proportional to the amount of foam. Thus, the water absorption of foam brick increases with the reduction in density. Higher foam content leads increase of pores and capillaries in brick structure, therefore the brick become weaker to resist on salt attack. XRD pattern of formed brick with 75% of foam addition on HL-GGBS coal ash brick portrays ettringite formation were attributed to disruption of brick structure. The use of coal ash with HL–GGBS and PC-GGBS combination as binder agent has been observed to be lightweight, low in water absorption, and advantageous in protection to salt attack compare to the conventional brick. The optimum proportion respected to the foam content is 50% in balance condition with approximately 1-2% of mass loss due to salt attack, 12-13% of water absorption and density significantly reduced to 1600kg/m^3.

Keywords – fly ash; bottom ash; hydrated lime; Portland cement; ground granulated blastfurnace slag (GGBS); foam; brick; density; water absorption; salt attack resistance

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ABBREVIATIONS

Al_2O_3	Aluminium Oxide
C	Calcites
C-A-H	Calcium aluminate hydrates
C-A-S-H	Calcium aluminate silicate hydrates
C-S-H	Calcium silicate hydrates
CA	Coal Ash
$Ca(OH)_2$	Calcium Hydroxide
CaO	Calcium Oxide
CW	Cotton waste
EPS	Expanded polystyrene
FaL-G	Fly ash-lime-gypsum
FCB	Fired clay brick
Fe_2O_3	Ferric oxide
GGBS	Ground granulated blastfurnace slag
h	Height of brick in m
H_2O	Water

HL	Hydrated lime
HL	Hydrated Lime
ISGS	Illinois State Geological Survey
l	Length of brick in m
LP-FA	Lime powder-fly ash
LPW	Limestone powder wastes
M	Mass of brick in kg
m_1	Initial weights
m_2	Mass of residue
M_d	Dry mass
M_s	Saturated mass
PC	Portland cement
RHA	Waste rice husk ash
SB	Sand brick
SEM	Scan electro microscope
SiO_2	Silicon Dioxide
UCB	Unfired clay brick
UPV	Ultrasonic pulse velocity

w	Width of brick in m
W_s	Water absorption
XRD	X-Ray Diffraction

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Bricks are conventionally made either by clay or shale since decades. Both of the main materials came from natural resources. Depletion of virgin resources may occur if clay and shale are continuously being extracted for brick manufacturing. In order to meet the need of sustainable development in manufacturing and construction industry, many researchers vigorously studied the alternative of main material for brick manufacturing. Various types of waste materials (Freidin, 2007; Hsu *et al.*, 2003; Lin, 2006; Rushad *et al.*, 2011; Shakir *et al.*, 2013) were studied to identify its suitability as brick material.

In Malaysia, coal is used as fuel for generation of electrical energy in thermal power. The combustion of coal will produce large quantities of bottom ash and fly ash which create disposal issues and leads to environmental problem and health hazards. Many research (Karthikeyan & Ponni, 2007; Kayali, 2005; Naganathan *et al.*, 2012; Turgut, 2010) have been carried out to look forward the methods and application in utilizing the enormous volume of coal ash in construction material manufacturing effectively.

In the production of brick, fly and bottom ashes have been used in brick making. In 2003, Government of India mandates the consumption of fly ash in brick manufacturing within 100 km radius from coal or lignite based thermal power plant (Rushad *et al.*, 2011). In Australia, fly ash is popular used as partial replacement of portland cement and consumed as main constituents in brick industry (Kayali, 2005). Illinois State Geological Survey (ISGS) also launched brick manufacturing program by utilizing fly ash from bituminous coal combustion in fired brick development (Chan, 2002).

A lot of researchers turned out with various of mix designation in their study to produce high performance of bricks by utilizing fly ash or/and bottom ash as a part of the brick constituents. Flash bricks made of 100% of fly ash as solid ingredient which constitute only fly ash and water produced compressive strength 24% higher and 28% reduction in density compared to the best standard of clay bricks (Kayali, 2005). The higher performance in strength of brick with utilization of fly ash was supported by Turgut (2010)'s research. Turgut (2010) claimed that the higher constituent of fly ash will increase the later strength of the masonry composite material. However, study made by Kumar (2002) in production of fly ash-lime-gypsum (FaL-G) bricks shows that the compressive strength of high percentage fly ash also influenced by the chemical reaction with other constituents in the mix proportion. The presence of the fly ash in the brick reduces the density of the bricks itself. Many studies find that, the low content of ash in the bricks decreases the percentage of water absorption (Kumar, 2002; Naganathan *et al.*, 2012; Turgut, 2010). On the other hand, Kayali (2005) discovered that his flash brick has higher water absorption as compared to the clay bricks.

Since the utilization of fly ash in the brick will produce lightweight brick type, it is more economic and practical in the usage of the bricks in construction. The low density bricks of course has great significance on loading floor, working comfortness, ease of construction, transportation capacity and also the cost and the number of bricks that can be produced per tonne of raw materials (Kayali, 2005; Kumar, 2002).

Based on the above mentioned researches, the compatibility of the coal ash as main or part of brick constituent is possible and proven. However, the percentage of the coal ash used, the type of binder agent and the amount of water in the mix proportion will affect the performance and the quality of the bricks. On the contrary, the ratio of different types of coal ash, the ratio of each binder agent used in the mix proportion and the method of brick production may produce different level of performance of the bricks. Therefore, it is essential to establish the optimum mix proportion of brick made of fly and bottom ashes with other agents as admixtures.

The published work on brick making using the combination of fly ash and bottom ash as target material and ground granulated blastfurnace slag (GGBS) used as the main component of the binder agent with combination with Portland cement or hydrated lime is still lacking. Foam was included in the concrete constituent to help in reducing the density of the materials. Hence, this study is looking forward the effect of amount of foam used in the coal ash bricks. Besides that, the effect of different types of binder agent in the coal ash brick on the durability of the bricks was investigated. In addition to that, the determination of water absorption and salt attack resistance was carried out to evaluate and analyse the effect of different types of blended binder agent as well as foam content in the coal ash bricks.

1.2 Problem Statement

The performance of bricks is measured by the strength and the durability. The durability of bricks subjected to the resistance of damage which caused by physical, chemical or mechanical actions. Previous study mostly focuses on the amount of fly ash in the brick material to produce lightweight and high strength of brick. However, the characteristic of fly ash is not the only component that contributes to the better quality of bricks. The roles of the binder agent are also significant to ensure the strength of bricks without compromising the durability itself. Research by Chindaprasirt & Pimraksa (2008), Cicek & Tanrıverdi (2007a), Kumar (2002), Rushad *et al.* (2011) and Turgut (2010) used lime as binder agent in their fly ash brick. However Kumar (2002) and Pimraksa & Chindaprasirt (2009) found that gypsum has more pronounced binding action than lime and at the same time can produce lightweight brick. Beside the raw material replacement with lightweight filler or binder to reduce the density of construction material, Karl & Weighlar (1980) found that artificially introduced air voids during mixing process would be advantageous. Introduction of air voids were carried out by the air entrainment application using foam agent. Nambiar & Ramamurthy (2008a) reported the stability and consistency of foamed concrete depends on the water content, foam volume added and the filler type.

Many researchers have studied and reported on the use of coal ash and GGBS as raw material for masonry brick. Some of researchers utilize the fly ash in brick or block production to produce either lightweight or better in durability (Chindaprasirt & Pimraksa, 2008; Cicek & Tanrıverdi, 2007a; Freidin, 2007; Hsu *et al.*, 2003; Karthikeyan & Ponni, 2007; Kayali, 2005; Kumar, 2002; Lin, 2006; Naganathan *et al.*, 2012; Rushad *et al.*, 2011; Turgut, 2010). Turgut (2010) proved that masonry composite material consists of fly ash satisfy the requirements in load bearing and non-load bearings. However, there is paucity of published work on durability performance of foamed brick. It is essential to determine the effect of foam content in different combination of blended binder to the water absorption and salt attack resistance of coal ash brick specimens. Kayali (2005) identified absorption capacity and salt attack resistance on the 100% fly ash brick indicate excellent performance compared to the conventional brick. There is no evidence of comparison between foamed brick and conventional brick, thus this study were compared the performance of water absorption and salt attack resistance of the foamed coal ash brick with the conventional specimens. Since the introduction of foam in brick making is considered new, the optimum amount of foam content was unrevealed. This study was performed to establish the optimum mix proportion of coal ash brick made by different content of foam. In addition to this, determination of water absorption and salt attack resistance were carried out in order to establish the correlationship between percentage of water absorption and percentage of mass loss respected to different percentage of foam.

1.3 Objectives of the Study

The objectives of the study are:

i. To determine the effect of foam content in different combination of blended binder to the water absorption and salt attack resistance of coal ash brick specimens.

ii. To compare the performance of water absorption and salt attack resistance of the coal ash brick with the conventional specimens.

iii. To establish the optimum mix proportion of coal ash brick made of different content of foam.

iv. To establish correlationship between the foam content to the water absorption and salt attack resistance of coal ash brick with respect to different content of foam.

1.4 Scopes of Study

The scope of study encompasses of the following activities :

In this study, the materials used to produce the coal ash bricks are coal ash, hydrated lime (HL) and ground granulated blastfurnace slag (GGBS). Other materials used are Portland cement (PC) and water. Coal ash consists of fly ash and bottom ash respect to 6 : 1 composition ratio by weight. The mix proportion of ten (10) series of coal ash brick with varies blended binder are given in the *Table 1-1*. The fly ash was obtained from Sejingkat Coal Power Plant which located 20 km from town of Kuching, Sarawak. The bottom ash was collected from Sultan Salahuddin Abdul Aziz Power Plant, Kapar, Selangor. The specimens were cured by air curing condition method under room temperature. Besides, three (3) different type of conventional brick were selected to compare those of brick performance in term of water absorption and salt attack resistance. The conventional bricks chosen were fired clay brick, unfired clay brick and sand brick.

Table 1-1 : Mix proportions of ten (10) series of coal ash bricks

Mix Designation	**Constituents of dry materials by weight (%)**				**% by total dry weight materials**	
	Coal Ash (CA)	Hydrated Lime (HL)	Portland Cement (PC)	GGBS	Water	Foam
M-a	70	30	-	-	30	-
M-1	70	10	-	20	30	-
M-2	70	10	-	20	30	25
M-3	70	10	-	20	30	50
M-4	70	10	-	20	30	75
M-b	70	-	30	-	30	-
M-1e	70	-	10	20	30	-
M-2e	70	-	10	20	30	25
M-3e	70	-	10	20	30	50
M-4e	70	-	10	20	30	75

In order to measure the water absorption of the coal ash brick specimens, the test method from BS EN 772-21 : 2011 was applied. Besides that, the specimens were tested for the salt attack resistance according to Australia and New Zealand Standards AS/NZS 4456.10 : 2003. XRD analysis was also performed for selected coal ash bricks with and without foam to detect the presence of chemical composition that contributed to the brick deterioration subjected to salt attack.

The results from the tests were analysed using statistical approach to determine the correlationship between the water absorption and the salt attack resistance of the resulted brick specimens with respect to the foam content.

1.5 Significance of Study

In Malaysia, coal ash brick is a relatively new construction material when compared to conventional clay bricks or sand bricks. The conventional bricks manufacturing potentially damage the environment due to continuously extraction of natural resources for the main raw material sources. Therefore, the use of by-product such as coal ash and ground granulated blastfurnace slag promoted the utilisation of waste material for the development of construction material components as substitution for the conventional materials. Due to the increase in landfill costs and current interest in sustainable development, recycling of coal ash has become a great concern. Besides that, production of coal ash brick without firing process contributes to reduction of gas emission to the environment. Thus, establishment of optimum mix proportion on coal ash brick can be used as a guideline in brick manufacturing industry to produce lighter and durable bricks.

Introduction of foam as air entrainment agent was reduced the brick density thus produced lightweight brick. Lightweight bricks offered substantial cost savings by providing less dead load, which eventually reduces size of structural elements. Besides that, lightweight bricks provide easy handling thus reduced transportation cost and time consume.

The factor limiting the usage of coal ash brick in applications where the durability is a concern due to lack of information and guidance on the material performance. This study were performed to evaluate the foamed coal ash brick regards to the water absorption and salt attack resistance. Besides that, the comparisons on the durability of foamed coal ash bricks with the conventional bricks were also carried out. Therefore, the best selection of material can be done to suit the application of bricks depend on the exposure to water and severe environment.

At the end of this study, there will be other option for utilisation of coal ash in order to reduce disposal cost, reduce pollution, creates revenue and business opportunities to the society.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Brick is one of the oldest manufactured building material and still most widely used until present (Beall, 2001). There are many types of brick which is made of different materials such as clay brick, concrete block and brick made by composite materials. There are many different shapes, sizes and types of brick. According to Beall (2004), ASTM standards cover building brick, facing brick, hollow brick, paving brick, firebox brick, glazed brick, chemical resistant brick and others based on appearance of the unit. The three (3) most widely used are building brick, face brick and hollow brick. Ordinary type of brick widely used in construction is clay brick which is usually found in rectangular shape with variety of sizes. Standard size for clay brick in a few countries is shown in *Table 2-1*.

Table 2-1 : Standard size of clay brick by country

Country	**Brick size (mm)**
Australia	230 × 110 × 76
India	228 × 107 × 69
United Kingdom	215 × 102.5 × 65
United States	194 × 92 × 57

Brick are often used as building material and road pavement. Building brick, made by machine of ground and tempered clay, has great uniformity of strength and colour. Such brick is made by pressing soft, stiff, or dry. The bricks are sorted according to hardness and colour, both largely resulting from their position in the kiln (Brady *et al.*, 2002). Paving brick is usually a hard-burned common brick. Paving brick for use in streets, walks, patios, and driveways must be strong, hard, and very dense. Paving bricks are manufactured to meet special needs with high compressive strength, resistance to abrasion, and low moisture absorption to increase durability against winter freezing and thawing cycles (Beall, 2001).

The following section describes the brick production techniques.

2.1.1 Brick Production

Bricks in construction may subject to load or non-load bearing. The types of raw material chosen and manufacturing method used in brick making will determine the quality and the characteristic of the bricks. The common brick types used in construction are clay brick and concrete brick. The following sub-sections elaborate the both types of brick.

2.1.1.1 Clay brick

The raw clay is the only material in production of clay bricks. During material preparation, initially the raw clay being washed to remove stone, soil and excessive sand. Then, the removal particle crushed into smaller particles and grounded to a powdered mix. After that, the manufacture of fired brick went through four stages of process start with forming, drying, burning and finally storage (see *Figure 2-1*). In the forming process, the clay thoroughly mixed with the measured amount of water to form plastic behaviour and extrudes and cutting following to the required shape and sizes. Before burning process, the shaped clay leaves for drying to permit evaporation of excess moisture during forming process. Then, finally the clay unit burn in the controlled firing kiln until ceramic fusion of the clay particles and brick hardening achieved (Beall, 2004).

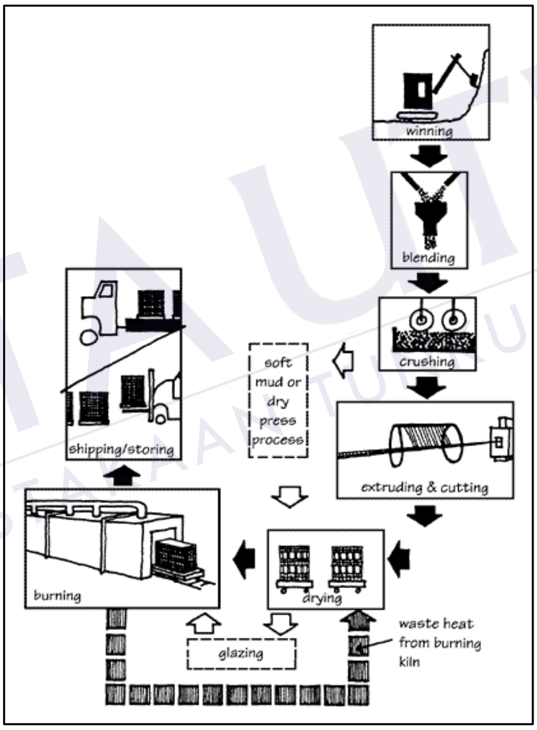

Figure 2-1 : Clay brick manufacturing process (Beall, 2004)

2.1.1.2 Concrete brick

Concrete brick is made from dry mix of cementitious materials, aggregates, water, and occasionally special admixtures. The material is moulded and cured under controlled conditions to produce a strong, finished block that is suitable for use as a structural building element. Both the raw materials and the method of manufacture influence strength, appearance, and other mechanical properties of the brick. Concrete masonry manufacturing consists of six phases which is start by receiving and storing raw materials, followed by batching and mixing process, moulding unit shapes, curing, cubing and storage, and finally delivery of finished units (see *Figure 2-2*). Autoclaved with high pressure steam was used during curing process. High-pressure steam curing enhances the quality and uniformity of concrete brick besides improve production rate and lowers cost of manufacturing.

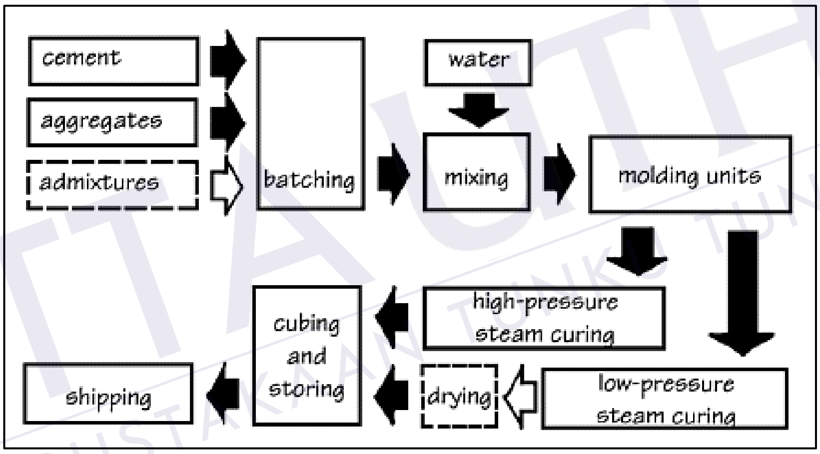

Figure 2-2 : Concrete brick manufacturing process (Beall, 2004)

2.2 Use of Waste Materials in Brick Production

In the recent years, the depletion of non-renewable resources such as clay mining to supply the main ingredients in the manufacturing of construction material has become critical day by day. Due to the increasing awareness on the sustainable construction, researchers face up the challenge to utilise the waste material into innovation of construction materials. The idea of recycling the waste materials does not only contribute to the conservation of natural resources but also can assist in solving global warming issues. At the same time, some researchers also introduced unfired brick (Chindaprasirt & Pimraksa, 2008) in order to reduce the combustion at the high kiln temperature which can reduced the emission of sulphur dioxide. Coal ash, granulated ground blastfurnace slag (GGBS), risk husk, recycle paper and saw dust are among the examples of waste materials used in the brick making.

Turgut & Algin (2007) have investigated the potential use combination of wood sawdust waste and limestone powder to produce lightweight and economic composite brick. Four series of mixture were prepared to identify the unit weight, water absorption, ultrasonic pulse velocity (UPV) as well as flexural and compressive strength. All test carried out resulted within compliance to the relevant international standard. Almost 65% of weight reduced with high-energy absorption capacity compared to the conventional brick.

Bilgin *et al*. (2012) from Turkey have studied the usability of waste marble dust as an additive material in brick production in order to minimizing pollution which cause by marble deposits, quarries and marble plant. The study found that addition of marble powder improves the physico-mechanical properties significantly. However, adding waste marble more than 10% of weight increases the water absorption and decreases the mechanical properties. Hardness of the brick structure directly proportion to the amount of marble powder.

Raut, Sedmake, Dhunde, Ralegaonkar, & Mandavgane (2012) were studied on the physical and mechanical properties of brick samples with paper pulp and binder to produce new brick material. By comparing this composition with conventional bricks, it produces lighter brick up to 50%, exhibits 9MPa which three times greater by addition 5-20% of cement to the composition as well as satisfies the requirements in BS 6073 for a building material to be used in the indoor structural applications.

Algin & Turgut (2008) were investigated on the utilization of cotton waste (CW) and limestone powder wastes (LPW) for producing new low cost and lightweight composite. The series of test carried out were compressive strength, flexural strength, ultrasonic pulse velocity (UPV), unit weight and water absorption. From the test results, the effect of 10–40% CW replacements in CW–LPW showed that sudden brittle fracture on the brick sample did not occur even beyond failure loads applied. Besides the weight reduction up to 60% from the conventional bricks, the compressive and flexural strength attained for concrete with 30% replacement level of CW satisfies the requirements in BS6073 for a building material to be used in the structural applications.

Ling & Teo (2011) have studied on the potential use of expanded polystyrene (EPS) beads and waste rice husk ash (RHA) as a renewable resource for producing brick. RHA which is identified as cementitious material was used as partial cement replacement, while the EPS was used as partial aggregate replacement in the mixes.

Five (5) mix proportion were designed and the properties were studied on compressive strength, water absorption and hardened density. It is found that densities of all EPS-RHA concrete brick samples less than 2000 kg/m^3 which classified as lightweight. In term of compressive strength, 10% RHA replacement is the optimum mix.

The following sections review utilisation of the coal ash as the material for brick production.

2.3 Coal Ash as the Alternative of Raw Material in Brick Production

Thermal power plants are the main source of power generation (Kolay & Singh, 2010; Sarkar *et al*., 2006). Thermal power plant coal generates large volumes of coal ash when burning coal as fuel (Naganathan *et al*., 2012; Turgut, 2010). Coal ash is a waste product of mineral fuel burning consists of fly ash and bottom ash.

Fly ash, a coal combustion residue is highly dispersible powder (Freidin, 2007; Sarkar *et al*., 2006). It is fine residue resulting from the combustion of powdered coal, transported by the flue gases and collected by the electrostatic precipators (Rushad *et al*., 2011). Fly ash is irregular shaped, containing lacy, vesicular, alumino-siliceous matter of complex composition and fine alumino-siliceous spheres (Sarkar *et al*., 2006). However, the chemical composition of fly ash depends on the coal used in combustion, method of combustion and removal efficiency of air pollution control device.

Bottom ash is part of the non-combustible residue of combustion in a thermal power plant or incineration of waste material. It is also refers to coal combustion and comprises traces of combustibles embedded in forming clinkers and sticking to hot sidewalls of a coal-burning furnace during its operation. The clinkers fall by themselves into the water and get cooled. In Malaysia, around 25,000 tonnes of bottom ash are produced by the incineration of 126,288 metric tonnes of industrial waste (Naganathan *et al*., 2012). The characteristic of ashes are influenced by the furnace type, capacity, temperature used, waste input and conditions of cooling (Chang & Wey, 2006; Freidin, 2007).

In Malaysia, the usage of coal in the thermal power plant significantly increased up to 9 million tonnes within 2000 to 2005 which produced 2 million of coal ash (Kolay & Singh, 2010). Incremental of the disposal coal ash sent to secure landfill is not a sustainable solution as it can contribute to deterioration of environment. In order to conserve the environment, generate revenue, reduce pollution and ensure sustainability, handling, disposal and utilization of coal ash become a challenging task. Moreover, the utilization of coal ash will reduce the ecological damage as well as the expenses caused by the disposal of these waste products.

Pei-wei *et al.*, (2007) found that addition of fly ash in the concrete mix can reduce the shrinkage, reduce expansion without compromising the compressive strength. Besides that, many researchers utilize the fly ash in brick or block production to produce either lightweight or better in durability (Chindaprasirt & Pimraksa, 2008; Cicek & Tanrıverdi, 2007a; Freidin, 2007; Hsu *et al.*, 2003; Karthikeyan & Ponni, 2007; Kayali, 2005; Kumar, 2002; Lin, 2006; Naganathan *et al.*, 2012; Rushad *et al.*, 2011; Turgut, 2010).

Meanwhile, Kayali (2005) from Australia introduced high performance bricks made of 100% of fly ash as the solid ingredient and water as main liquid called Flash Bricks. The Flash Bricks production require firing process at 1000-1300°C same like production of conventional bricks. He found that the compressive and tensile strength, absorption capacity and salt attack resistance on the Flash Bricks indicate excellent performance. Then, Freidin (2007) in his research found that the combination of alkali-activated fly ash as cementless binder, utilisation of bottom ash as an aggregate with addition of water glass can form a water-stable concrete-like building materials (CBM).

On the other hand (Chindaprasirt & Pimraksa, 2008; Cicek & Tanrıverdi, 2007a; Kumar, 2002; Rushad *et al.*, 2011; Turgut, 2010) used lime based material as the binder agent in their fly ash bricks. Turgut (2010) proved that masonry composite material made of limestone powder and fly ash satisfy the requirements in load bearing and non-load bearings. Even without the presence of Portland cement as a binder agent, fly ash which exhibits both pozzolanic and cementitious properties can be self-hardened in the presence of water due to its higher Calcium Oxide (CaO) content. The reaction and hydration process of the fly ash are as follows (Turgut, 2010) :

$Ca(OH)_2 + SiO_2 + H_2O \rightarrow (CaO)_x (SiO_2)_y (H_2O)_z$ …… (*Equation 2-1*)

(calcium silicate hydrates [C-S-H])

$Ca(OH)_2 + Al_2O_3 + H_2O \rightarrow (CaO)_x (Al_2O_3)_y (H_2O)_z$ …… (*Equation 2-2*)

(calcium aluminate hydrates [C-A-H])

$Ca(OH)_2 + Al_2O_3 + SiO_2 + H_2O \rightarrow (CaO)_x (Al_2O_3)_y (SiO_2)_z (H_2O)_w$ …… (*Equation 2-3*)

(calcium aluminate silicate hydrates [C-A-S-H])

$Ca(OH)_2 + Al_2O_3 + SO_3 + H_2O \rightarrow (CaO)_x (Al_2O_3)_y (CaSO_3)_z (H_2O)_w$ …… (*Equation 2-4*)

(calcium aluminate calcium sulphate hydrates)

The calcium-silicate-hydrate (C-S-H) gel which occupying about 50% of the paste volume is the most important cementing component of concrete. C-S-H is responsible for the engineering properties of concrete including setting, hardening and strength development because if forms a continuous layer that binds together the original cement particles into a cohesive whole. According to Cicek and Tanrıverdi, (2007) C-S-H and C-A-S-H phases contribute to the hardening of fly ash or lime materials since fly ash contains considerable amounts of Al_2O_3 and SiO_2. Formation of C-S-H and C-A-S-H gels from hydration and pozzolanic reaction is critical to strength development where as C-S-H may reduce the permeability and enhanced durability (Obuzor, Kinuthia, & Robinson, 2012). When fly ash and GGBS dissolved in water, presence of Al^{3+} ions during hydration process of Portland cement will contribute of forming Calcium Aluminate Silicate Hydrates (C-A-S-H). The benefits of C-A-S-H can be achieved by adding supplementary cementitious materials that contain reactive aluminum to concrete mixture (Hunnicutt, 2013). More production of C-A-S-H results intensify in strength, minimise the pore space, increase in density thus volume stability and improvement in permeability (Obuzor *et al*., 2012).

In the other point of view, Chindaprasirt & Pimraksa, (2008) and Cicek & Tanrıverdi, (2007) studied lime based fly ash brick making under different methods of curing. Cicek & Tanrıverdi (2007) from Turkey studied on lime based steam autoclaved fly ash bricks and found that higher lime addition had no significant effect on the mechanical strength of the specimen. The optimum mixture composition consist of 68% fly ash, 20% sand and 12% lime with 20 MPa brick forming pressure. Under 1.5 MPa autoclaving pressure for 6 hours duration, results for the compressive strength, water absorption and thermal conductivity were 10.25 MPa, 40.5% and 0.34 $Wm^{-1}K^{-1}$ respectively. However, the addition of lime may fasten the curing time for unfired bricks (Chindaprasirt & Pimraksa, 2008).

Limestone also been used in the production of masonry fly ash bricks with other kinds of waste materials such as gypsum (Kumar, 2002) and soil (Rushad *et al*., 2011).

Research by Kumar (2002) shows that fly ash-lime-gypsum is a hydraulic binder that is reactive upon addition of water but gypsum has more pronounced binding action compared to lime. The role of lime as a good binder agent supported by Rushad *et al*., (2011)'s research where compressive strength of bricks increases with lime proportion.

In addition, Shakir *et al*., (2013) was used different combination of waste materials in production of fly ash bricks. They concluded that manufacture of bricks using combination of billet scale, quarry dust and fly ash is feasible. However, the presence of billet scale and quarry dust cannot produce lightweight brick which is one of the main reason of the researchers choose the fly ash as the brick constituent in their research.

2.4 Properties of Brick Incorporating Waste Materials

Generally, performance of bricks depending on the constituent of raw material used as well as method of curing in brick making. The following is some of the mechanical properties that used to measure the performance in term of strength and the durability of bricks.

2.4.1 Compressive Strength

Bricks are good in compressive strength but weak in tensile strength (Beall, 2001). There are many factors that influencing the strength of bricks. Karthikeyan & Ponni (2007) stated that care taken and method production of brick may affect the performance of brick strength. Kumar (2002) observed that the process of hardening is influenced by temperature, thus he claimed that the higher curing temperature exhibits higher strength of bricks. In the other point of view, the addition of admixtures such as lime powder, quarry dust and water glass will improve the strength of fly ash bricks (Cicek & Tanrıverdi, 2007a; Freidin, 2007; Karthikeyan & Ponni, 2007; Shakir *et al*., 2013; Turgut, 2010). However, in Cicek & Tanrıverdi (2007)'s study, brick forming pressure, autoclaving pressure and curing time does not give significant effect to the compressive strength. Enhancement of strength and durability leads to optimisation of resource, cost effectiveness and environment conservation (Obuzor *et al*., 2012).

2.4.2 Density of Brick

Density can be classified in fresh state and hardened state. Fresh density usually required for designing mix proportion and casting control purposes while hardened density related to the physical properties. Density of brick is directly proportion to the mass of the brick on the same volume of brick. Density of bricks depends on the material used in the brick production. Utilization of fly ash can reduce the density of the bricks up to 28% (Kayali, 2005). This is supported by Turgut (2010) that the dry density of brick were inversely proportional with the fly ash content while Lin (2006) indicated that bulk density of the bricks increased when the fly ash slag content increased. From study done by Ramamurthy, Nambiar, & Ranjani (2009), introduction of foam and replacement of sand with fly ash help in reducing the density with an increased strength. Above all, lightweight brick significantly given huge effect to the overall structure loadings, ease of handling during construction, transportation capacity and rate of brick production (Kayali, 2005; Kumar, 2002).

2.4.3 Water Absorption

Water absorption is the potential of the brick permit the excess water into the brick. The absorption capacity of the brick is very important to determine the performance of the brick (Kayali, 2005). Ling & Teo, (2011) revealed that full water curing lightweight concrete bricks produced lowest percentage of water absorption compared to air-dried curing bricks. Kumar (2002), Naganathan *et al*., (2012) and Turgut (2010) found that water absorption percentage in the fly ash brick proportional to the fly ash content. Therefore, the ability of water absorb into bricks depends on the curing method and properties of material in brick proportion. According to study done by Kumar (2002) on fly ash-lime-gypsum bricks, the increase in density of these brick, the water absorption will be reduced. High volume of pore in brick structure contribute to lower value in density, thus the ability of water being absorb into the brick become higher. Too low capacity of water absorption is not desired since it tends to reduce the durability of mortar joints in rainy day. However, very high water absorption capacity may result in volume changes and may damage the bricks which lead to cracking. The material may start losing strength with time if the water absorption is high especially when exposed to unprotected environment (Oti, Kinuthia, & Bai, 2009).

2.4.4 Salt Attack Resistance

One of the brick durability problems is exposure to salt attack because salt either in liquid or vapour form can easily absorb into masonry. Salts originates from various sources such as air pollution, soil, inappropriate treatment, deicing salts, sea spray or interaction between building material may enter a porous material through condensation, capillarity, infiltration and/or hygroscopicity (Charola, 2000). Due to evaporation of salt solution in the brick structure, the salt crystals may form and grow in the pores. The generated crystallization pressure which is higher than the existing tensile strength is sufficient to damage the brick microstructures (Bakar, Ibrahim, & Johari, 2011). Depending to the materials of the bricks, exposure condition, rate of drying and the temperature, the constrained salt crystal in the pore resulted deterioration on the surface of the bricks (Bricks & Pavers Technical Manual). Burgess (2001) in his study on brick clay found the resistance to salt attack was correlated to the water absorption. Kayali (2005) reported the utilisation of 100% of fly ash in brick making shows that the resistance to salt attack after 15 cycles of salt exposure was much better compare to the conventional clay bricks. Therefore, the salt attack resistance may depend to the pore volume in the brick structure.

2.4.5 Thermal Conductivity

Thermal conductivity measures the ability of the brick to conduct heat. According to study on unfired clay masonry bricks by Oti, Kinuthia, & Bai (2010), the thermal conductivity depends to the density, moisture content and mineralogical composition of the brick constituents. It was found that the unfired brick made using a lime-activated-GGBS has higher thermal conductivity compared to unfired brick which made of Portland cement-activated GGBS. The conductivity value depends to the composition of material but not significantly affected by the density (Neville, 2011). Turgut (2010) in his study on masonry composite material by utilising limestone and fly ash claims value of thermal conductivity decreases with increasing amount of fly ash similar to the finding by Cicek & Tanrıverdi (2007) on their autoclaved fly ash bricks. In short, the presence of fly ash lower the thermal conductivity compared to the traditional clay bricks. So that, by utilising the fly ash brick with low thermal conductivity can reduce the cost on heating or cooling the building (Cicek & Tanrıverdi, 2007a).

2.5 Binder Agent in the Coal Ash Brick

Binder agent plays the most significant role to produce high performance of bricks. Many research were carried out to determine the suitability of other materials to be use as the brick constituent. The characteristic and properties of the binder agent are important to ensure the reaction between/with other raw materials can produce cementitious properties. The following sub-sections entail type of binder agent been used in the coal ash brick.

2.5.1 Lime

The common lime based admixture used in building construction materials made of limestone. Lime provide plasticity behaviour in the mortar where as it is easily spread over the small surface indentations, pores and the irregularities in the brick units. It is also provide strong physical bond besides improves water retention. Utilisation of lime in the bricks unit permit longer drying process so that enough water is maintained for proper curing and cementitious hydration (Beall, 2001). Reaction of lime which

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